APPENDIX A

PREDICTED PATHOGEN CONCENTRATIONS AND CONSUMER HEALTH RISKS RESULTING FROM BODY-CONTACT RECREATION ON THE EAST AND WEST BRANCH STATE WATER PROJECT RESERVOIRS

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FINAL REPORT TO:

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Executive Summary

Swimming and other body-contact recreational activities have been identified by the USEPA, California Department of Health Services, and other public health professionals as a potential source of microbiological contamination of recreational waters. Fecal shedding and accidental fecal release by infected individuals can result in high numbers of pathogenic organisms, including *Cryptosporidium*, *Giardia*, and rotavirus, being input into surface waters. Nevertheless, little information is available on the importance of this source of pathogens to surface waters. Moreover, the potential health implications resulting from body-contact recreation on reservoirs used as source drinking water supplies are not well-understood.

This study was undertaken to quantify, using available theoretical and empirical data, the impacts of body-contact recreation on water quality in the four southern State Water Project (SWP) reservoirs. Mean annual *Cryptosporidium*, *Giardia*, rotavirus and poliovirus concentrations for the SWP reservoirs were predicted using results from a detailed simulation study conducted for MWD's Diamond Valley Lake (formerly known as the Eastside Reservoir) in conjunction with available recreator and reservoir data. Dose-response models were then applied to predicted concentrations following treatment to provide an estimate of health risks resulting from consumption of recreator-impacted SWP water. Hydrodynamic and transport simulations were also conducted to evaluate the short-term temporal and spatial dynamics of coliform and pathogen concentrations in Lake Perris resulting from heavy recreational use of the beaches there. Simulation results are compared with coliform monitoring data collected during the summer of 1999.

Lake Perris was found to have the highest level of recreational use, both in absolute numbers and when normalized to its epilimnetic volume (9.5 recreators/acre-foot/yr). Castaic Lake had a projected use intensity about one-half that of Lake Perris, while Pyramid Lake was somewhat lower than Castaic Lake. Silverwood Lake had the lowest use intensity (2.6 recreators/acre-foot/yr) of the four SWP reservoirs. These differences in use intensity translated to predicted pathogen concentrations that varied rather significantly among the reservoirs. Median predicted annual *Cryptosporidium* concentrations ranged from 0.22 oocysts/100 L in Silverwood Lake to 0.85 oocysts/100 L in Lake Perris. Predicted concentrations of *Giardia* were much lower than those for *Cryptosporidium*, and ranged from 0.008 - 0.031 cysts/100 L. Predicted median annual rotavirus levels were considerably higher than either *Giardia* or *Cryptosporidium* in the

reservoirs (71- 267 pfu/100 L). Poliovirus concentrations ranged from 1.5 - 5.7 pfu/100 L. Results were also presented using cumulative probability distribution functions (cdf) in which concentrations were plotted as a function of cumulative probability. The principal benefit from use of cdfs can be perhaps best demonstrated by considering the statistical implications associated with use of median values. It was stated above that the median predicted annual concentration of *Cryptosporidium* in Lake Perris was 0.85 oocysts/100 L. Since by definition the median value of a population indicates that one-half of a population or set of observations lays below the median value and one-half lays above it, there is a 50% chance that the predicted annual *Cryptosporidium* concentration in Lake Perris will be *above* 0.85 oocysts/100 L. At higher cumulative probability, the likelihood of exceeding the corresponding concentration decreases. For example, at the 95% cumulative probability, there is only a 5% chance that the annual concentration in Lake Perris will exceed 16.6 oocysts/100 L. In the interest of protecting public health, MWD considered cumulative probabilities of 95 and 99%. For the SWP reservoirs, predicted pathogen concentrations at the 95% level were ~10 - 100x higher than the median values.

Application of the appropriate dose-response models also yielded probabilistic descriptions of annual risk of infection to consumers. Such an approach allows one to define the probability of exceeding the EPA's target of 1 infection per 10,000 consumers per year. For *Cryptosporidium*, the probability of exceeding 1 infection per 10,000 consumers per year is approximately 65% for Lake Perris, 53% for Castaic Lake, 45% for Pyramid Lake and 40% for Silverwood Lake. Prospects for infection due to *Giardia* were much lower (<1% for all reservoirs).

Transport simulations conducted for Lake Perris predicted a rather complex circulation pattern within the reservoir that tended to limit dispersion of fecal coliform from beach areas. Simulations predicted fecal coliform concentrations at Perris Beach that increased substantially through the late morning and early afternoon, peaked at approximately 3 p.m. with concentrations approaching 120 cfu/100 mL, and then fell sharply in the late afternoon and early evening. Wind-induced currents were predicted to move coliform in a northeasterly direction down the beach toward tower 5, where a small clockwise gyre transported coliform along the point and then moved the plume in a southwesterly direction out several hundred meters from the beach area. Dispersion and inactivation lowered the concentrations to ~2 cfu/100 mL or less by midnight. Because of the longer inactivation half-life, *Cryptosporidium* was predicted to be transported further into the reservoir than fecal coliform.

These simulation results were in reasonable accord with available fecal coliform monitoring data; samples collected at Perris Beach at approximately noon during the summer weekends of 1999 yielded a mean from a log-normal distribution of 15.3 ± 5.3 cfu/100 mL, which was in good agreement with a predicted concentration of 24 cfu/100 mL. Predicted and observed concentrations near the buoy line were both below 2 cfu/100 mL. Cumulative probability distribution functions developed from coliform monitoring data indicate that fecal coliform concentrations at noon will exceed the DHS simple sample limit of 400 cfu/100 mL at a probability of about 2.5% for Perris Beach and 5.5% for Moreno Beach. Simulation results do indicate, however, that the probabilities for exceeding the DHS level will be higher later in the afternoon. Given the importance of transport processes in defining exposure, measurements of water currents within the lake, additional monitoring both near the beaches and in the main body of the lake, and more comprehensive modeling are needed to fully define the recreator and consumer health risks resulting from body-contact recreation.

Introduction

Swimming and other recreational activities that involve direct human contact with water have been found to negatively impact water quality in some settings (Rose *et al.*, 1987; Calderon *et al.*, 1991; Kramer *et al.*, 1996). The impacts are generally more pronounced for water bodies that are subject to intense use, *i.e.*, with high numbers of recreators in limited areas or on small water bodies. In such settings, fecal coliform concentrations can exceed 1600 cfu/100 mL (*e.g.*, CCWD, 1999). Because of difficulties and costs associated with sampling and detection, concentrations of pathogens in recreator-impacted waters and the associated health risks to consumers and recreators remain poorly understood.

As a result, numerical simulations have recently been used to estimate pathogen concentrations in source drinking water reservoirs (Yates et al., 1997; Anderson *et al.*, 1998). An extensive simulation study of Diamond Valley Lake (formerly the Eastside Reservoir) was conducted for the Metropolitan Water District of Southern California (MWD). In that study, Monte Carlo (MC) techniques were incorporated into a finite segment-based pathogen transport model to predict pathogen concentrations in the reservoir under different recreational scenarios (Anderson *et al.*, 1998). The model divided Diamond Valley Lake (Eastside Reservoir) into 38 lateral segments, with each lateral segment further divided into an upper, epilimnetic zone and a lower, hypolimnetic zone, for a total of 76 segments. The concentrations of pathogens (*Cryptosporidium*, *Giardia*, rotavirus and poliovirus) within each segment of the reservoir were then predicted based upon inputs associated with body-contact recreational activities, and losses due to inactivation, export and sedimentation. The model considered advective and dispersive flux between segments, age-weighted infection rate of body-contact recreators, mass of fecal material shed by a recreator, pathogen content of the fecal material, frequency of accidental fecal releases (AFRs), mass of AFR, the inactivation rate constant for the pathogen, epilimnetic settling velocity of the pathogen, cross-sectional area for epilimnion-hypolimnion exchange, and the hypolimnetic settling velocity. The inputs from fecal shedding and AFRs were summed over the number of recreators on a given segment per day (Yates *et al.*, 1997; Anderson *et al.*, 1998). Monte Carlo techniques were incorporated into the model to define relevant features about each of the recreators using the reservoir on a given day, *e.g.*, the occurrence of infection and AFRs, mass of feces shed, pathogen content of feces, and so on. MC techniques were also used to conduct an uncertainty analysis in which 5000 simulations were conducted using randomly selected uncorrelated parameter sets based on values derived from the literature (Anderson *et al.*, 1998).

Results from the Monte Carlo analyses were used to develop cumulative distribution and probability density functions for *Cryptosporidium*, *Giardia*, rotavirus, and poliovirus concentrations in the reservoir. This probabilistic approach was deemed necessary given the uncertainty in pathogen shedding rates and other model input parameters (Anderson *et al.*, 1998). *Cryptosporidium* was the pathogen of greatest concern due to its slow rate of inactivation in the environment and its resistance to chlorination. Predicted pathogen concentrations were then used with dose-response models to predict probability of infection.

Results from the MWD study were subsequently used to estimate pathogen concentrations in Contra Costa Water District's Contra Loma Reservoir and the associated risks to consumers and recreators (Anderson, 1999a). Calculations for the Contra Loma Resevoir, which involved scaling recreational use rates, epiliminion volumes, and other factors to Diamond Valley Lake (Eastside Reservoir), yielded results that were consistent with more detailed hydrodynamic simulations for the Contra Loma Reservoir (Anderson, 1999b) and with risk calculations using *E. coli* and enterococcus monitoring data in conjunction with health effects relationships developed by Dufour (1984) (Anderson, 1999c).

Results from an analysis of body-contact recreational impacts on water quality are presented for the four southern State Water Project (SWP) reservoirs (Lakes Castaic, Pyramid, Silverwood and Perris). The analysis includes predictions of pathogen concentrations based upon scaling of results from the Diamond Valley Lake (Eastside Reservoir) study, and application of dose-response models to predict corresponding health risks to consumers. Numerical simulations describing circulation within Lake Perris and the transport of coliform and *Cryptosporidium* away from beach areas were also conducted. Results from the analyses were compared with available monitoring data.

Estimated Pathogen Concentrations in State Water Project Reservoirs

With some assumptions, results from the MWD study can be used to estimate pathogen concentrations in the SWP reservoirs. As was done in the Contra Loma

Reservoir study, it is assumed that parameters describing pathogen loading and loss are valid for application to the SWP reservoirs. Recreational use rates, reservoir volumes, and other site specific parameters will be used to estimate concentrations in the SWP reservoirs based on levels predicted for Diamond Valley Lake (Eastside Reservoir) (Anderson, 1999a; Anderson *et al.*, 1998; Yates *et al.*, 1997).

Recreational Use and Reservoir Data

The SWP reservoirs vary significantly in their size (Table 1). Silverwood Lake is the smallest of the reservoirs, with a surface area of 976 acres and a capacity of 74,970 acre-feet at full pool, while Castaic Lake is the largest (323,700 acre-feet capacity). It is noteworthy that all are well below the 800,000 acre-foot capacity of Diamond Valley Lake (Eastside Reservoir). Lake Perris is the shallowest of the SWP reservoirs at a mean depth at full pool of 57 feet, while the west branch reservoirs of Castaic and Pyramid have mean depths nearly 3x larger (Table 1). In the context of these calculations, the total reservoir volume is less important than the epilimnetic volume, however. Because these reservoirs are generally stratified during the summer when most body-contact recreational activities occur, pathogen inputs will largely be restricted to the warm, well-mixed upper portion of the water column (Anderson *et al.*, 1998). Average epilimnetic volumes were calculated from capacity-elevation data for the reservoirs (DWR, pers. comm.) assuming depths to the thermocline of 7 m for Lakes Castaic and Pyramid, 25 m for Lake Silverwood, and 8 m for Lake Perris (Lund *et al.*, 1993; DWR, pers. comm., MWD, pers. comm.) and average summer surface elevations of 1497, 2570, 3348, and 1585 feet, respectively (DWR, 2000) (Table 2).

Table 1. SWP reservoir data (at full pool)[a].

Reservoir	Surface Area	Capacity	Mean Depth
	-- acres --	-- acre-feet --	-- feet --
Castaic	2235	323,700	145
Perris	2325	131,500	57
Pyramid	1298	171,200	132
Silverwood	976	74,970	77

[a]data from G. Faulconer, DWR

Total annual visitation to the SWP reservoirs ranged from 207,000 – 1,007,460 visitors per year for the 1998-1999 fiscal year (Table 2), with approximately one-half of the total recreators engaging in body-contact recreational activities at the reservoirs (DPR, pers. comm.). Recreational activities at Lakes Perris, Silverwood and Pyramid include swimming, personal watercraft use, and water skiing, although swimming is not allowed at Castaic Lake. These values compare with projected annual total recreator use rates for Diamond Valley Lake (Eastside Reservoir) of approximately 380,000 – 700,000 per year or 50,000 – 290,000 body-contact recreators per year (depending upon the recreational scenario).

Normalization of body-contact recreational use to epilimnetic volume provides a useful measure of overall intensity of use and information about the level of pathogen loading due to recreational activities to each of the reservoirs. Results from such a normalization are provided in Table 2.

Table 2. Recreational data and body-contact recreational use normalized to epilimnion or mixed layer volume.

Reservoir	Annual Visitation[a]	Body-Contact Recreator Use[b]	Epilimnion Volume	Use-Volume Normalization
	-- yr^{-1} --	-- yr^{-1} --	-- acre-feet --	-- recreators/acre-feet/yr --
Castaic	890,573[b]	225,000[c]	45,490	4.95
Perris	1,007,460	504,000	52,930	9.52
Pyramid	207,000	103,000	28,500	3.61
Silverwood	329,357	165,000	63,000	2.62

[a]Annual visitation data (FY 98-99): Castaic: M. White, DPR; Perris: DPR website (parks.ca.gov/districts /loslagos/lpsra.htm); Pyramid: M. Apante, DWR; Silverwood: DPR website (parks.ca.gov/districts/loslagos /slsra.htm).
[b]Calculated from annual visitation data assuming 50% of all visitors will engage in body-contact recreational activities (DPR, pers. comm.)
[c]Calculated assuming one-half of all body-contact recreators will use Castaic Lake for PWC and water-skiing, while one-half will use Castaic Lagoon for swimming and other body-contact activities (DPR, pers. comm..). Thus ~225,000 body-contact recreators were assigned to the main reservoir.

Based on this normalization, one sees that Lake Perris is the most heavily impacted of the SWP reservoirs by body-contact recreation, with 9.5 body-contact recreators/acre-foot/yr in the upper, epilimnetic portion of the water column. The other reservoirs have normalized use rates approximately one-quarter to one-half of that of Lake Perris, broadly comparable to that projected for Diamond Valley Lake (Eastside Reservoir) under the boating+skiing+PWC recreational scenario (3.03 body-contact recreators/acre-feet/year). Nevertheless, the SWP reservoirs have normalized use rates well-below that caculated for the Contra Loma Reservoir near Antioch, CA, (38.1 body-contact recreators/acre-feet/year) (Anderson, 1999).

Subject to a number of assumptions, the comparison of normalized SWP use rates to that predicted for Diamond Valley Lake (Eastside Reservoir) provides a convenient means by which one can extrapolate the results from Monte Carlo simulations conducted for Diamond Valley Lake (Eastside Reservoir) to the SWP reservoirs. The limitations to this approach will be discussed later in this report.

Lake Perris

The predicted median annual average *Cryptosporidium* concentration in the epilimnion of Diamond Valley Lake (Eastside Reservoir) was 0.27 oocysts/100 L under the full basin boating+skiing+PWC recreational scenario (Yates *et al.*, 1997; Anderson *et al.*, 1998). When corrected for recreator and volume differences, one estimates a median *Cryptosporidium* concentration of 0.85 oocysts/100 L for Lake Perris. For comparison, while more than 3x higher than that predicted for Diamond Valley Lake (Eastside Reservoir), it is only approximately one-quarter the median *Cryptosporidium* concentration of 3.38 oocysts/100 L predicted for the Contra Loma Reservoir (Anderson, 1999a). The predicted median concentration of *Giardia* in Lake Perris was lower than that for *Cryptosporidium* (0.031 cysts/100 L), although predicted poliovirus and rotavirus concentrations were higher (5.7 and 267 pfu/100 L, respectively).

The full cumulative probability distribution functions for *Cryptosporidium* and the other pathogens scaled from the Diamond Valley Lake (Eastside Reservoir) simulations are presented in Fig. 1. Fig. 1 shows that, by definition, one-half of the predicted annual average concentrations of *Cryptosporidium* fell below the median value of 0.85 oocysts/100 L, and one-half of the predicted concentrations were greater than the median value. In the interest of public health, MWD considered concentrations at the 95 and 99% levels (wherein only a 5 and 1% probability of underestimating pathogen concentrations exists) (Yates *et al.*, 1997). At the 95% level, this corresponds to an annual average *Cryptosporidium* concentration of 16.6 oocysts/100 L in the upper 8 m of the water column. The predicted concentration of *Giardia* at the 95% level was 0.8

cyst/100 L, while concentrations of poliovirus and rotavirus were about 44 and 3055 pfu/100 L, respectively (Fig. 1).

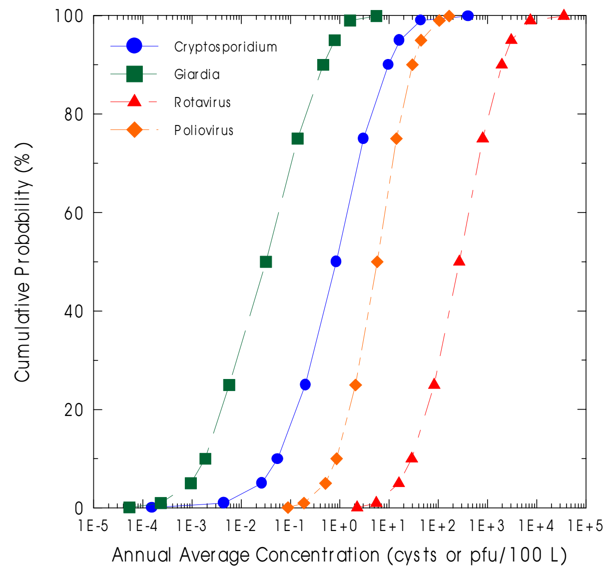


Fig. 1. Predicted annual average epilimnetic pathogen concentrations in Lake Perris.

<u>Silverwood Lake</u>

Estimated annual average epilimnetic pathogen concentrations in Silverwood Lake are shown in Fig. 2. The projected median concentration of *Cryptosporidium* was 0.22 oocysts/100 L, a value only one-fourth as large as that for Lake Perris. At the 95% level, the predicted concentration was 4.41 oocyts/100 L, much lower than that predicted for Lake Perris (16.4 oocysts/100 L). Median concentrations for the other pathogens ranged from 0.008 cysts/100 L for *Giardia*, to 1.5 pfu/100 L for poliovirus and 71 pfu/100 L for rotavirus. The lower predicted concentrations in Lake Silverwood result from both the lower level of body-contact recreational use relative to Lake Perris, and the operations of the reservoir (Table 2). Large flows through the reservoir result in a well-mixed water column with limited thermal stratification and short hydraulic retention times (~1.5 – 2 months) (DWR, pers. comm.). As a result, pathogen inputs from recreators, considered to be effectively confined to the warm, well-mixed epilimnion, are dispersed over a much greater depth in Lake Silverwood when compared with Lake Perris or the other SWP reservoirs.

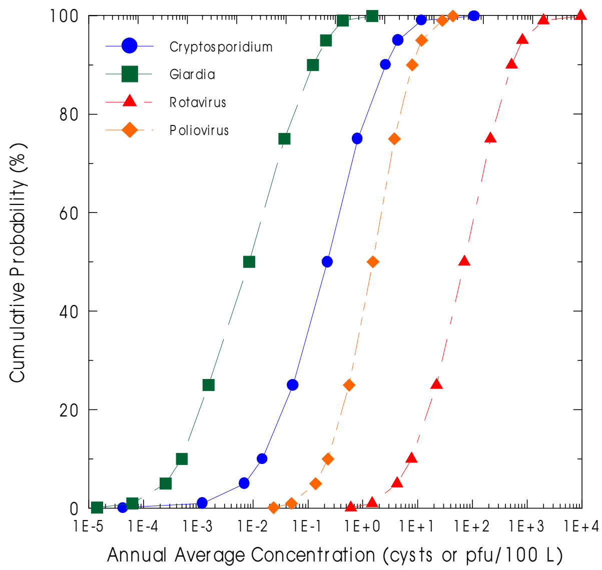


Fig. 2. Predicted annual average epilimnetic pathogen concentrations in Silverwood Lake.

<u>Castaic Lake</u>

Concentrations of pathogens in Castaic Lake were intermediate between those predicted for Lake Perris and Lake Silverwood (Fig. 3). Median *Cryptosporidium*, *Giardia*, poliovirus and rotavirus were 0.43, 0.016, 2.9, and 13.4 per 100 L, while concentrations at the 95% level were 8.3, 0.4, 22.3 and 1530 per 100 L, respectively.

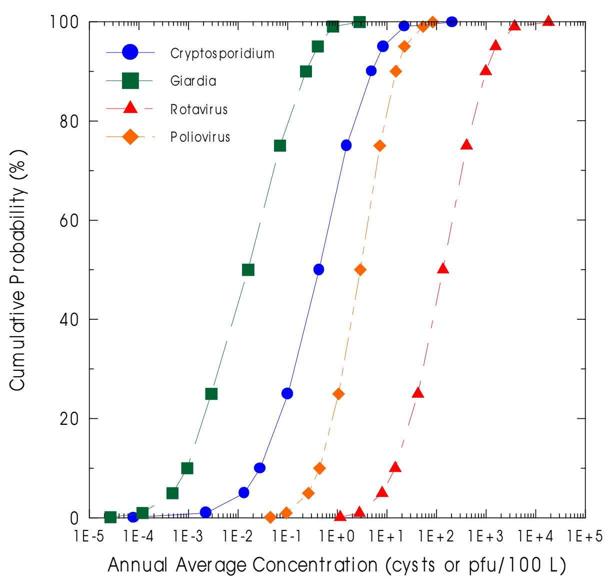


Fig. 3. Predicted annual average epilimnetic pathogen concentrations in Castaic Lake.

Pyramid Lake

Pathogen levels in Pyramid Lake were lower than those predicted for Lake Perris and Castaic Lake, but slightly higher than those for Silverwood Lake. The median *Cryptosporidium* concentration was 0.31 oocysts/100 L, *Giardia* was 0.01 cysts/100 L, poliovirus was 2.1 pfu/100 L and rotavirus was 98 pfu/100 L. Concentrations at the 95% cumulative probability were 6.08,0.29,16.3 and 120 per 100 L, respectively (Fig. 4).

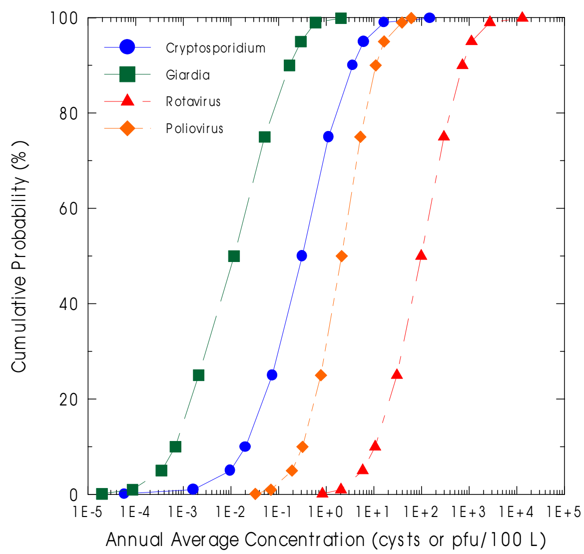


Fig. 4. Predicted annual average epilimnetic pathogen concentrations in Pyramid Lake.

Comparison of Predicted Concentrations with Available Monitoring Data

Limited monitoring data exists for the SWP reservoirs. Of the four southern SWP reservoirs, only Lake Perris is monitored on a regular basis. Samples are collected weekly at the beaches during the summer by DPR staff and the results are reported to the Riverside County Health Department. Samples are analyzed for total and fecal coliform. Since swimming is not allowed on Castaic Lake, the Los Angeles County Health Department does not monitor the lake. (Swimming is restricted to a treated off-line lagoon.) Although Silverwood Lake has two designated swim beaches, water quality at the beaches is not monitored by State Parks, DWR or the San Bernardino County Health Department. Analogously, monitoring is not conducted at Pyramid Lake. There is no regular monitoring for pathogens at any of the reservoirs.

MWD has conducted periodic monitoring of their filtration plant influent for *Cryptosporidium*, however. Monitoring data collected from October 1994 – December 1997 was plotted in the form of a cumulative distribution function and compared with predicted results for the SWP reservoirs (Fig. 5). Plant influent concentrations are broadly comparable to the predicted mean annual concentrations for Castaic Lake, although it should be noted that the monitoring data represent single-sample values that correspond to a point in time rather than an annual average value. Nevertheless, the observed distribution is qualitatively reproduced by the cdfs developed for the SWP reservoirs. Moreover, the average predicted median concentration of 0.45 oocysts/100 L for the four SWP reservoirs is in general agreement with the mean *Cryptosporidium* concentration of 0.36 oocysts/100 L for Diamond Valley Lake (Eastside Reservoir) source waters (Yates *et al.*, 1997), which include both East Branch SWP and Colorado River waters.

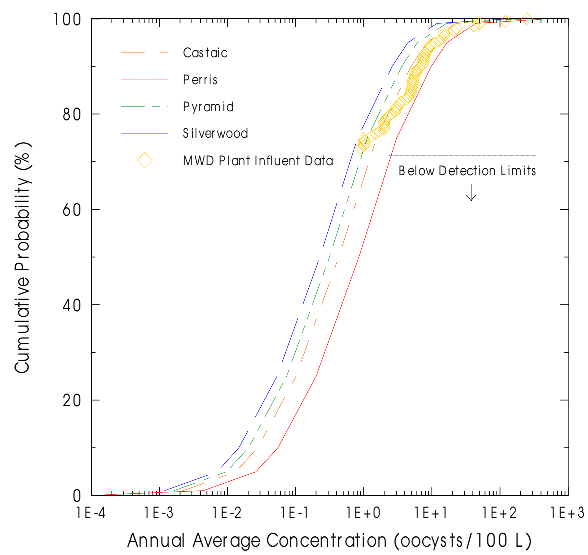


Fig. 5. Predicted SWP and MWD plant influent Cryptosporidium concentrations.

Health Risks Resulting from Body-Contact Recreation

Predicted pathogen concentrations were then used to calculate health risks to consumers resulting from body-contact recreation on the SWP reservoirs. For these calculations, risks resulting from body-contact recreation were quantified following the risk assessment approach used in the Eastside Reservoir study (Yates *et al.*, 1997). In this approach, the probability of contracting an infection or illness is a function of both the exposure and the infectivity of the pathogen. Exposure to consumers is governed by the pathogen concentration in the source water, any inactivation during transit from reservoir to the treatment plant, and the removal efficiency at the treatment plant. In the following calculations, the probabilities of contracting an infection due to *Cryptosporidium* and *Giardia* are considered.

Cryptosporidium

For these calculations, a 1-day transit time from reservoir to the treatment plant was assumed. Based upon an inactivation rate constants of 0.08 d^{-1} for *Cryptosporidium* (Anderson *et al.*, 1998), inactivation of *Cryptosporidium* during transport resulted in an 8% reduction in concentration entering the treatment plant. A 2-log removal for *Cryptosporidium* at the plant was assumed following USEPA guidance. It should be noted that, based on particle removal studies by MWD at their treatment plants, a 2.5 log removal was used in the MWD study.

Daily exposure to the consumer was calculated based on the concentration of pathogens in water delivered to consumers and the volume of water consumed per day, assumed to be 2 L/day (Regli *et al.*, 1991; Haas *et al.*, 1993). Recreator-contracted infection was calculated assuming ingestion of 30 mL of untreated water (Yates *et al.*, 1997). The probability of contracting an infection due to *Cryptosporidium* was then determined using an exponential dose-response model, which assumes that the daily probability of infection, P_i, is given by:

$$P_i = 1 - exp(-rN) \qquad (1)$$

where r is a parameter describing the dose-response curve and N is the exposure (*e.g.*, number of oocysts). A best fit value of r of 0.0042 was used in the Diamond Valley Lake (Eastside Reservoir) study and will also be used here (Yates *et al.*, 1997). The annual risk of infection was calculated from the daily probability using the relationship (Yates *et al.*, 1997):

$$P^d = 1 - (1 - P_i)^d \qquad (2)$$

where d is the number of days of exposure (here assumed to be 365).

Using the projected median *Cryptosporidium* concentrations for the SWP reservoirs, a 1-day transit time from reservoir to treatment plant, and a 2 log removal efficiency at the treatment plants, one estimates a median annual risk of infection of 0.64

to 2.39 infections per 10,000 consumers per year resulting from use of the recreator-impacted SWP reservoir waters (Table 3). These consumer risk levels are up to an order of magnitude higher than the median value of 0.26 infections per 10,000 per year predicted for the Diamond Valley Lake (Eastside Reservoir) under the boating+skiing+ personal watercraft recreational scenario (using a 2.5-log removal efficiency), but lower than the value of 3.1 infections per 10,000 per year predicted for the Contra Loma Reservoir (also calculated assuming 2.5-log removal at the treatment plant).

In addition to the probability of infection, one can predict the prospects of illness and mortality resulting from consumption of the water. Assuming morbidity and mortality ratios of 61 and 0.0001 %, respectively (Bennett *et al.*, 1987; Yates *et al.*, 1997) and using the median *Cryptosporidium* concentrations for the SWP reservoirs, one calculates 0.39 – 1.46 illnesses per 10,000 people per year and $6.4x10^{-7}$ – $2.4x10^{-6}$ deaths per 10,000 people per year resulting from the use of recreationally-impacted SWP reservoirs as a drinking water source (Table 3).

Table 3. Consumer risk assessment results: *Cryptosporidium.*

Reservoir	Infections	--- Median Values --- Illnesses	Mortality	Probability of Exceeding EPA
	--- per 10,000 consumers per year ---			%
Castaic	1.20	0.73	$1.2x10^{-6}$	53
Perris	2.39	1.46	$2.4x10^{-6}$	65
Pyramid	0.88	0.54	$8.8x10^{-7}$	45
Silverwood	0.64	0.39	$6.4x10^{-7}$	40

One notes that the median risk of infection for both Castaic Lake and Lake Perris exceed the EPA level of 1 infection/10,000/year, while Pyramid and Silverwood Lakes remains below this standard. Using the data in Figs. 1-4 and the dose-response model, one can calculate the cumulative distribution function for risk of infection from *Cryptosporidium* (Fig. 6). The figure shows that there exists about a 60% probability that the risk of infection from consumption of treated Lake Silverwood water will be below the EPA's target of 1 infection per 10,000 consumers per year (Fig. 6). The higher pathogen concentrations in Lake Perris result in a correspondingly lower probability of remaining below the EPA's target (35%). Predicted consumer risks for Pyramid and Castaic Lakes were intermediate between these two reservoirs, with the prospects of remaining below the EPA's target of 1 infection per 10,000 per year at about 45% and somewhat more than 50%, respectively (Fig.6). Thus, there is a two-thirds chance that use of Lake Perris water will result in an infection rate exceeding 1 per 10,000 per year, but only a 40% chance for Silverwood Lake (Table 3).

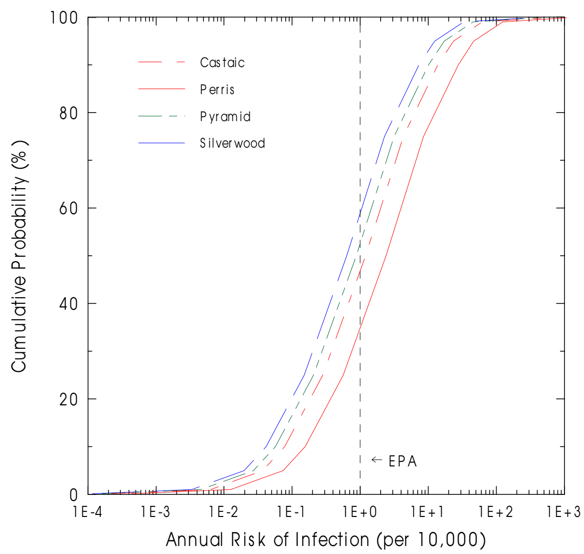


Fig. 6. Predicted annual risk of infection to consumers due to Cryptosporidium.

The annual risk of infection increases with increasing cumulative probability (or decreasing exceedance probability); at the 95% level, the annual risk of infection from *Cryptosporidium* increase to 46.6, 23.4, 17.1, and 12.4 per 10,000 per year for Perris, Castaic, Pyramid and Silverwood Lakes, respectively.

<u>*Giardia*</u>

Risk calculations were also conducted for *Giardia*. Based upon human feeding trials, an exponential dose-response model for *Giardia* has been developed (eq 1), with a best-fit value for *r* of 0.0198 (Yates *et al.*,1997). Using the median *Giardia* concentrations predicted in the reservoirs, a transit time from reservoir to plant of 1 day, an inactivation rate of 1.375 d^{-1} (Anderson *et al.*, 1998), and 3-log removal at the treatment plant, one calculates consumer infection rates about 200 times lower than those calculated for *Cryptosporidium* (Table 4). Prospects for illness and mortality are also correspondingly lower.

Cumulative distribution functions developed for the SWP reservoirs indicate that even at the 99% level (that is, where there exists only a 1% probability of underpredicting infection), risk of infection from *Giardia* remains below the 1 per 10,000 per year level (Fig. 7). Thus, body-contact recreational activities do not appear to have a significant effect on giardiasis consumer risk levels (Table 4).

Table 4. Consumer risk assessment results: *Giardia.*

Reservoir	Infections	--- Median Values --- Illnesses	Mortality	Probability of Exceeding EPA
	--- per 10,000 consumers per year ---			%
Castaic	0.0058	0.0023	5.8×10^{-9}	0.1
Perris	0.0115	0.0046	1.2×10^{-8}	0.2
Pyramid	0.0042	0.0017	4.2×10^{-9}	<0.1
Silverwood	0.0031	0.0012	3.1×10^{-9}	<0.1

[a]Morbidity ratio of 0.4 (Meyer, 1990)
[b]Mortality ratio of 10^{-6} (Meyer, 1990)

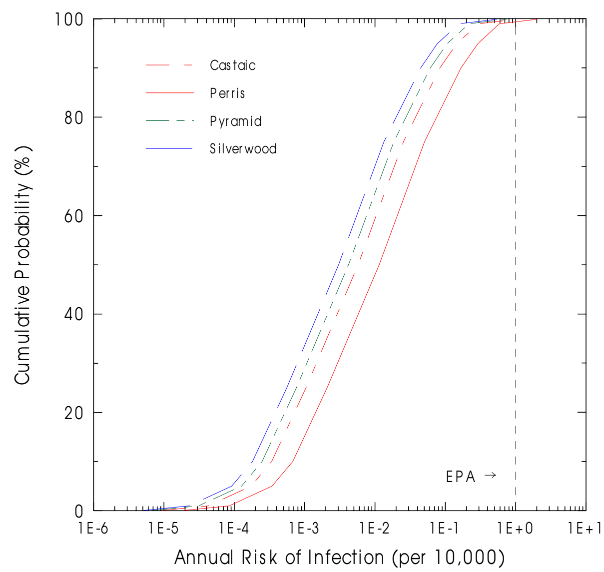


Fig. 7. Predicted annual risk of infection to consumers due to Giardia.

Rotavirus

Infectivity of rotavirus has been described using a beta-Poisson model of the form:

$$P_I = 1-(1+N/\beta)^{-\alpha} \quad (3)$$

where α and β are fitted dose response parameters of 0.24 and 0.42, respectively.

Application of this dose-response model, in conjunction with predicted rotavirus concentrations for the SWP reservoirs, inactivation during transit, and 4-log removal at the treatment plant, yields predicted median infection rates of up to hundreds of infections per 10,000 per year. Community health data and other evidence point to lower prevalence of illness than predicted in the above calculations, however. Furthermore, recent work suggests lower rates of fecal shedding of rotavirus than assumed in the Diamond Valley Lake (Eastside Reservoir) study. Additionally, the capacity for virus removal beyond 4-logs at the plants led MWD to discount rotavirus risk to water consumers, and identified *Cryptosporidium* as a more probable health concern (Yates *et al.*, 1997). Nevertheless, rotavirus risk to recreators, even in light of decreased fecal shedding, remains a concern (Anderson, 1999c).

<u>Poliovirus</u>

A suitable dose-response model for poliovirus was not identified in the literature. Nevertheless, the lower concentrations in the water column relative to rotavirus, and the efficacy of treatment at removing viruses from the water suggests that poliovirus should represent limited health concerns relative to other pathogens assuming normal plant operation.

Potential Limitations and Additional Considerations

While the scaling of the Diamond Valley Lake (Eastside Reservoir) results to SWP reservoirs based upon recreator use and reservoir volume data is a useful way of estimating local pathogen concentrations, some potential limitations to this approach need to be considered. The potential limitations to this approach include those that arise due to the different hydraulic and limnological characteristics of the reservoirs and from different patterns of recreational use. The model developed for Diamond Valley Lake (Eastside Reservoir) allowed for both lateral and limited vertical gradients in pathogen concentrations within the reservoir which were defined by its morphometric and hydraulic properties. These properties can be expected to differ quite significantly for the SWP reservoirs.

Furthermore, body-contact recreation on Diamond Valley Lake (Eastside Reservoir) resulted from water skiing, personal watercraft use, and/or limited body-contact boating (*e.g.*, kayaking) which was either distributed across the entire reservoir or restricted to the east basin. While this recreational scenario is comparable to that for Castaic Lake, the other SWP reservoirs include swimming at beach site(s). Thus, potentially high levels of pathogen inputs would also be localized; such inputs are different from the distributed inputs considered for Diamond Valley Lake (Eastside Reservoir). Due to the slow rate of inactivation of *Cryptosporidium*, the pathogen of primary concern, however, transport away from the beach and into the open water is expected to be significant.

This can be evaluated for Lake Perris through some simple calculations assuming that swimmers at the beach areas are major sources of bacteria and pathogens to the lake. Since pathogen inactivation follows a first-order process, the concentration reaching the outlet can be estimated from:

$$C = C_0 e^{-kt} \tag{4}$$

where C is the concentration at the dam, C_0 is the concentration at the beach, k is the inactivation rate coefficient and t is the travel time. Assuming a transport velocity of 1 cm/s and a distance from Perris Beach to the outlet tower of ~2500 m, one calculates transport time of 2.9 days. Inactivation rate coefficients and percent of fecal coliform, *Cryptosporidium, Giardia* and rotavirus removed during transport to the outlet tower assuming a 2.9 day transport time are given in Table 5.

Table 5. Inactivation rate coefficients and organism loss during transport from beach to outlet assuming a travel time of 2.9 days.

Organism	k (d^{-1})	% Removed
Fecal coliform	1.0[a]	94
Cryptosporidium	0.08[b]	21
Rotavirus	0.30[b]	58
Poliovirus	0.58[b]	81
Giardia	1.37[b]	98

[a] Thomann and Mueller (1987)
[b] Yates *et al.* (1997)

These calculations show two important features. First of all, based upon available median inactivation coefficients taken from the literature for freshwater samples at 20-25 °C, only ~6 % of the fecal coliforms would be expected to remain after transport from Perris Beach to the reservoir outlet, while almost 80% of the *Cryptosporidium* is expected to persist (Table 5). It seems reasonable then to conclude that, although recreational use patterns and limnological features of the Eastside Reservoir and Lake Perris are quite different, the slow rate of inactivation of *Cryptosporidium* in natural waters allows extension of results from Diamond Valley Lake (Eastside Reservoir) to Lake Perris. Similar conclusions hold for the other SWP reservoirs. In fact, sensitivity analysis conducted as part of the MWD study found that simulation results for *Cryptospordium* were overall relatively insensitive to transport parameters (Yates *et al.*, 1997). Model results were highly sensitive to the loading parameters, however (*i.e.*, the number of body-contact recreators, the infection rate in the recreator population, and the pathogen content of the feces of infected individuals).

It bears noting that, due to the higher rates of inactivation for the other pathogens considered, transport becomes more important in accurately estimating their local concentrations in the reservoir. The high inactivation rate of *Giardia* results in low predicted concentrations at the outlet, with percent removal comparable to that estimated for fecal coliforms. Rotavirus will be removed to a larger extent than *Cryptosporidium* although less than that predicted for *Giardia* or coliform. For these more readily inactivated pathogens, inactivation during transit within the distribution system may also become significant. In the above risk calculations for *Cryptosporidium*, a 1-day transit time was assumed, which resulted in an 8% reduction in concentration during transit from reservoir to treatment plant. A more rigorous analysis of hydrodynamics and transport of pathogens within Lake Perris is given in a subsequent section.

In addition to the issues related to inactivation and transport, it bears noting that additional factors may serve to influence pathogen concentrations and associated risks relative to the levels estimated in the preceding sections. Those factors include (i) a different age distribution for the recreator population for the SWP reservoirs as compared with Diamond Valley Lake (Eastside Reservoir); (ii) treatment efficiencies at some plants receiving SWP water may differ significantly; (iii) the additivity of risks; (iv) the issue of elevated concentrations and risks during the summer; and (v) other inputs of pathogens to the reservoir.

The age distribution of the recreator population is an important factor in defining the overall or age-weighted infection rate and, ultimately, in establishing the pathogen loading to the reservoir. Numerous researchers have reported higher incidence of infection and pathogen excretion from children than from adults (*e.g.*, Melnick and Rennick, 1980; Sealy and Shuman, 1983; Champsaur *et al*, 1984). In the Diamond

Valley Lake (Eastside Reservoir) study, for example, the rate of *Cryptosporidium* infection of children <7 years of age was 3.5x higher than older children and adults (7.7 vs. 2.2%, respectively). Since the body-contact recreational activities on Diamond Valley Lake (Eastside Reservoir) (*i.e.*, boating, skiing and personal watercraft use) are directly comparable to those at Castaic Lake, it seems likely that the age distribution from the Diamond Valley Lake (Eastside Reservoir) study would be appropriate. The SWP reservoirs with swimming beaches, however, would presumably include a significant population of younger recreators. Thus one might anticipate a somewhat higher age-weighted rate of infection and, ultimately, higher pathogen concentrations and risk levels in the other SWP reservoirs (especially Lake Perris). The magnitude of this can be estimated by considering that only 3.6% of the recreator population for Diamond Valley Lake (Eastside Reservoir) is <7 years old and thus yields an age-weighted infection rate of 2.4%. Although an exact age breakdown of recreators for Lake Perris or the other SWP reservoirs with swimming is not available, if one assumes that 25% of the swimmers are <7 years old, one estimates an infection rate weighted over all recreators of about 3.6%. This value is 50% higher than that used in the Eastside Reservoir study and consequently also used to estimate pathogen levels in the SWP reservoirs. Based on this, then, one might anticipate that the actual probability of infection is about 50% higher than the risk levels described in the preceding section.

Assumptions about treatment plant efficiencies also influence the estimated risk levels associated with use of the SWP reservoirs. The risk to consumers was calculated assuming a 2 log removal of *Cryptosporidium* at the treatment plant following EPA guidance. In the Diamond Valley Lake (Eastside Reservoir) study, a 2.5 log removal of *Cryptosporidium* at the filtration plant was assumed based upon particle removal studies conducted by MWD (Yates *et al.*, 1997). Removal efficiencies at the filtration plant will directly affect consumer risk levels; higher removal at the plant would result in lower pathogen concentrations in water delivered to consumers and lower corresponding risk to consumers relative to the levels presented above, while plant failure would substantially increase consumer health risks.

An additional point about consumer risk levels is based on the additivity of risk of infection. The risk calculations in the preceding sections are presented as individual risks due to *Cryptosporidium* and *Giardia*. Due to the additivity of risks, however, it should be recognized that the total risk of infection to consumers is the sum of all individual risks.

Thus the total risk of infection will necessarily be higher than the risk of cryptosporidiosis, for example, in Fig. 6.

Beyond the annual average pathogen concentrations and corresponding risk levels, Yates *et al.* (1997) also considered the short-term or peak risks that are present during the summer during high levels of recreational use. Risks associated with delivery of the water during the summer were generally about 4x higher than the corresponding annual risk levels. Moreover, peak events associated with, *e.g.*, AFRs, can result in concentrations and risk levels an order of magnitude or more higher than the mean annual values. These risks are not quantified in this study.

Finally, a fifth factor which could increase overall risk to consumers and recreators in the reservoir beyond that discussed above is the potential for pathogen inputs from additional sources within the watershed (*i.e.*, non-body-contact inputs). Inputs as a result of stormwater runoff, sewage leaks, agricultural activities and other sources have not been explicitly evaluated in this study.

Hydrodynamic and Transport Simulations of Lake Perris

In addition to the annual average pathogen concentrations predicted for the SWP reservoirs, hydrodynamic and transport simulations were conducted for Lake Perris. Simulations were conducted for Lake Perris because of the high intensity of recreational use relative to other SWP reservoirs (Table 2), frequency of beach closings, and availability of monitoring data.

Simulations were conducted using a 2-dimensional, depth-averaged finite element model applied to the epilimnion. While such an approach will yield a less accurate representation of the velocity field within the lake relative to a full 3-dimensional simulation, near-shore currents are thought to be reasonably represented. Bathymetric data was taken from available topographic and lake maps. A finite-element mesh for the epilimnion was developed with about 250 nodes (Fig. 8).

Simulations for a typical summer weekend day were conducted using available meteorological data and an assumed total daily body-contact recreational use of 3750 swimmers at each of the two beaches. Meteorological data was taken from a nearby CIMIS station; ~7 summer days were randomly selected from the database and averaged to derive a typical hourly windspeed and wind direction (Fig. 9).

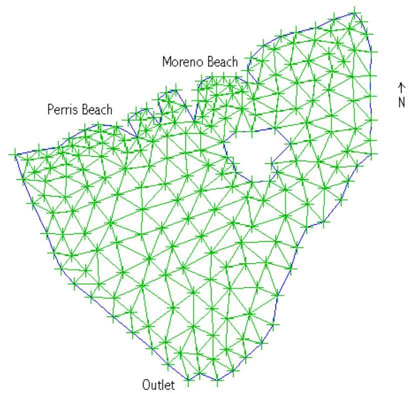


Fig. 8. Finite element mesh for Lake Perris simulations.

Wind speed was found to vary substantially over the day; the wind speed averaged ~0.5 m/s through much of the night and early morning, reached a minimum around 7 a.m., and then increased significantly throughout the remainder of the morning and into the afternoon. Wind speed reached a maximum value of 4.7 m/s at 4 p.m., and then decreased sharply through the rest of the afternoon and early evening (Fig. 9a). Winds were generally out of the southwest (Fig. 9b).

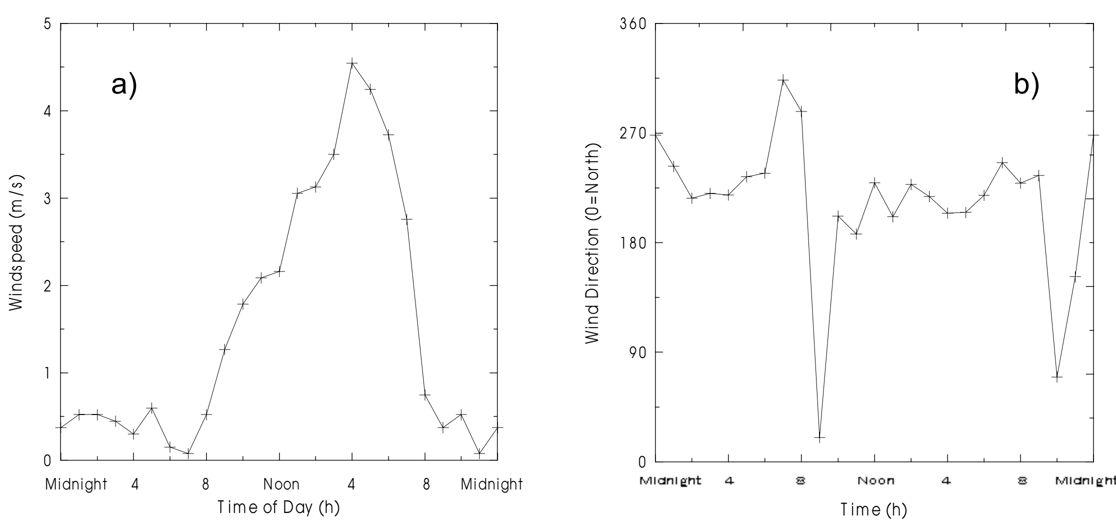


Fig. 9. Meteorological conditions used in simulations: a) wind speed and b) wind direction (N = 0 degrees)

In response to the wind energy acting on the surface of the lake, a rather complex velocity field within the lake was set up (Fig. 10). Mid-lake velocities of 0.1-0.5 cm/s were

predicted, while higher velocities (~1-2 cm/s) were predicted near shore. Interestingly, the model predicts small clockwise gyres near Perris and Moreno Beach, with somewhat higher velocities predicted for Perris Beach relative to Moreno Beach. It should be noted that the 1000 gpm pumps, which have been included in these simulations, were not found to have a significant effect on circulation patterns at the beach areas when compared to simulation results in which the pumps were turned off. Such an observation is consistent with empirical data that show that high coliform concentrations and beach closures have continued even after installation of the systems. Thus, it appears that wind energy controls circulation at the beach areas.

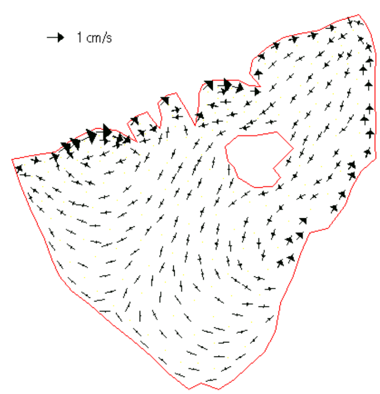


Fig. 10. Predicted typical afternoon circulation pattern in Lake Perris.

<u>Predicted Fecal Coliform Concentrations</u>

Assuming that one-half of the body-contact recreators are swimmers at the two beaches, that each swimmer sheds 3.8×10^7 fecal coliforms (Rose *et al.*, 1991), and an inactivation rate of 1.0 d^{-1} for fecal coliform (Yates *et al.*, 1997), one can calculate the fecal coliform concentrations as a function of time and space within Lake Perris. Concentrations at Perris Beach were predicted to increase steadily through the morning and afternoon, and reach a maximum concentration of almost 120 cfu/100 mL at approximately 3 p.m. (Fig 11). Strong temporal trends in coliform concentrations near swimming areas have been previously confirmed by monitoring (Anderson, 1999b).

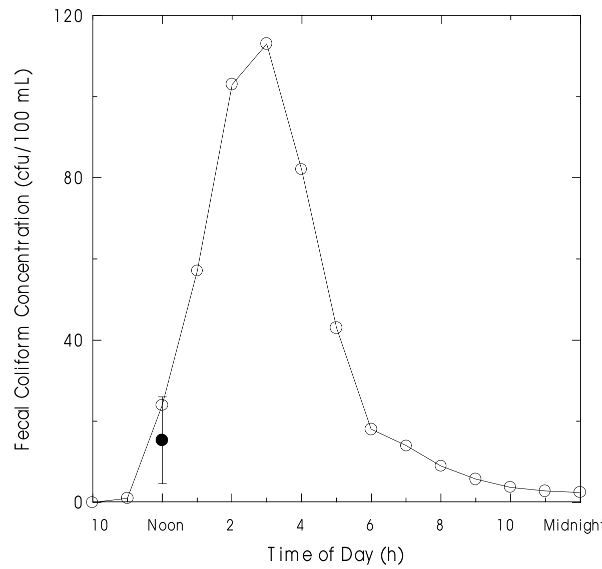
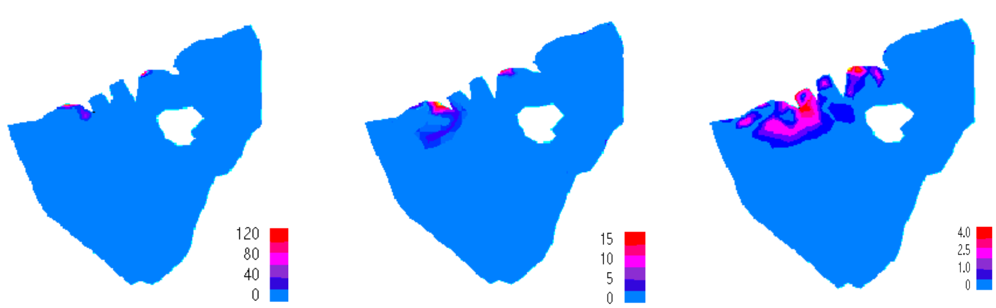


Fig. 11. Predicted fecal coliform concentrations at Perris Beach (open symbols). Mean concentration ± two standard deviations from 1999 summer sampling is also shown.

A plot of the spatial distribution at 3 p.m. of fecal coliform within the reservoir shows that concentrations quickly fall away from the beach areas, although there is some convection down Perris Beach due to wind-driven surface currents (Fig. 12a). At 7 p.m., several hours after peak beach use, the center of the coliform plume has migrated downfield from Perris Beach, with dispersion and inactivation lowering the peak concentration to about 15 cfu/100 mL. Some clockwise transport following the weak gyre has also occurred, resulting in the coliform plume extending out ~400 m from shore with concentrations ~3.5 cfu/100 mL. By comparison, relatively little transport away from Moreno Beach has occurred (Fig. 12b). It appears that the more protected nature of the Moreno Beach embayment limits wind-driven circulation within Moreno Beach and may result in higher and more persistent concentrations of fecal coliform relative to Perris Beach under equivalent use intensity.



a) 3 p.m. *b) 7 p.m.* *c) Midnight*

Fig. 12. Predicted summer weekend fecal coliform concentrations in cfu/100 mL in L. Perris.

By midnight, peak concentrations have been reduced to ~4 cfu/100 mL, with convection and dispersion further smearing out the coliform plume (Fig. 12c). Nevertheless, the plumes are fairly limited in areal extent, and generally do not extend out more than ~500 m from the beach areas under the meteorological conditions used in the simulations. The rapid rate of inactivation also limits migration of high concentrations of the bacteria away from the beach areas.

Comparison with Available Fecal Coliform Monitoring Data

Monitoring at Lake Perris for the summer of 1999 (Memorial Day - Labor Day) included sampling at lifeguard towers 3 and 5 at Perris Beach and at towers 6, 8 and 10 at Moreno Beach (J. Gillis, 1999). Samples were collected every Sunday between noon and 1 p.m. Fecal coliform concentrations at the two beaches ranged from <2 - 1600 cfu/100 mL, with an arithmetic mean concentration for all sites at each beach of 57 ± 107 cfu/100 mL at Perris Beach and 124 ± 257 cfu/100 mL at Moreno Beach. These values are well above the median concentrations at the beaches (15 and 26.5 cfu/100 mL for Perris and Moreno Beach, respectively). As is generally observed, the monitoring data better conformed to a log-normal distribution; applying such a distribution, one calculates mean values of 15 and 37 cfu/100 mL for the two beach sites. One notes that these values are much closer to the median concentrations, supporting the assumption of a log-normal distribution as the appropriate statistical descriptor for the monitoring data. Concentrations at buoys demarcating the outer edge of the swimming area were 2 cfu/100 mL or less in all instances except the July 11, 1999 sampling (J. Gillis, 1999).

Monitoring data are quite consistent with simulation results which predicted concentrations of 24 cfu/100 mL at Perris Beach at noon (Fig. 11), and concentrations generally ~1 cfu/100 mL offshore at the buoy line. Concentrations were predicted to approach 120 cfu/100 mL at the beach during typical peak weekend use with limited transport away from shore (concentrations generally <2 cfu/100 mL or less).

Following the approach used to present data for pathogen concentrations and consumer risks, cumulative distribution functions were developed from the fecal coliform monitoring data at Perris and Moreno Beaches (Fig. 13). One can see that fecal coliform data follow quite closely the sigmoidal shape predicted for the pathogens (*e.g.*, Figs. 1-4). The figure also shows that, for a given probability, coliform concentrations are consistently higher for Moreno Beach than for Perris Beach. Assuming the sample size is sufficient to characterize the statistical distribution of fecal coliform concentrations at the beaches during the summer weekends, Figure 13 also allows one to estimate the probability of exceeding the DHS single sample limit of 400 cfu/100 mL. The data indicates that the probability of exceeding the DHS value is about 2.5% for Perris Beach and 5.5% for Moreno Beach. Because of the predicted temporal variations (Fig. 11), however, it can be expected that the probabilities of exceeding the DHS guidelines later in the afternoon will be higher than those shown in Fig. 13. Thus, fecal coliform levels during the summer are generally significantly higher at the beaches than further out into the reservoir, with concentrations at the beaches potentially exceeding DHS single-sample and 30-day limits.

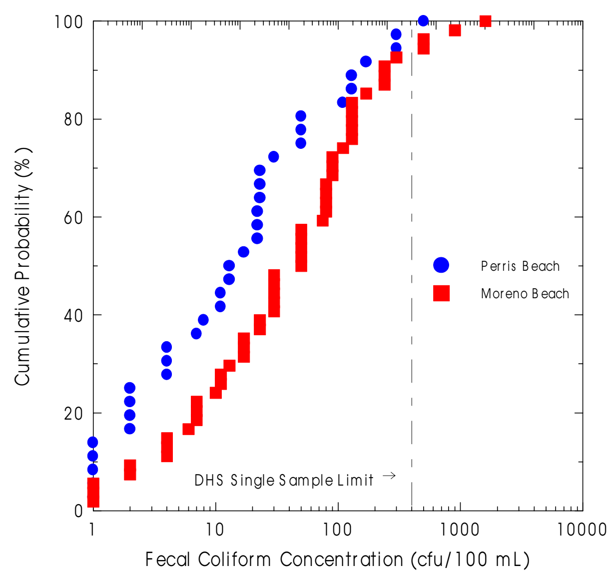
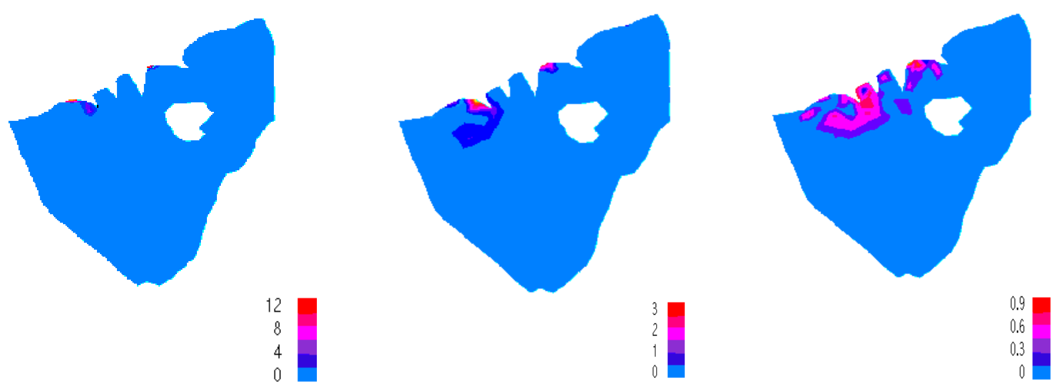


Fig. 13. Cumulative probability distribution functions developed from fecal coliform monitoring data for Perris Beach and Moreno Beach at Lake Perris.

<u>Predicted *Cryptosporidium* Concentrations</u>

Simulations were also conducted to elucidate predicted *Cryptosporidium* concentrations near the beach. For these simulations, concentrations were calculated using the median values from the Diamond Valley Lake (Eastside Reservoir) study and assumed 0.1 g fecal material was shed per swimmer, an infection rate of 2.5%, a pathogen concentration of the feces of 10^6 oocysts/g, and an inactivation rate of 0.08 d^{-1}. Accidental fecal releases (AFRs), previously shown to be potentially very important in defining pathogen loading, are excluded from this deterministic calculation due to the stochastic nature of the loading. Results for *Cryptosporidium* are shown in Fig. 14. The spatial distribution of *Cryptosporidium* is similar to that for fecal coliform (Fig. 12), although the lower loading rate results in much lower maximum concentrations (note units) (Fig. 14). Predicted *Cryptosporidium* concentrations at the beach increased during the late morning, reached a maximum concentration of almost 12 oocysts/100 L at approximately 3-4 p.m. (Fig. 14a), and then subsequently decreased as a result of convective and dispersive processes (Fig. 14b,c). The low rate of inactivation limits the importance of this removal process relative to fecal coliform. Moreover, the long inactivation half-life for *Cryptosporidium* (~8.7 days) relative to fecal coliform (~0.7 days) indicates that transport away from the beach and to the outlet tower can become significant. Thus, *Cryptosporidium* concentrations in the epilimnion will tend to increase over a period of weeks during the summer, while fecal coliform concentrations will tend to be locally and transiently high during periods of high use, and then rapidly decrease during the evening and during periods of limited recreational use (*e.g.*, weekdays).



a) 3 p.m. *b) 7 p.m.* *c) Midnight*

Fig. 14. Predicted summer weekend Cryptosporidium concentrations in oocysts//100 L in L. Perris.

The data depicted in Fig. 14 can also be presented in terms of distance from the beach or outlet tower. Concentrations along a transect from Perris Beach to the outlet tower were determined for 3 p.m., 7 p.m. and midnight (Fig. 15). High concentrations were observed in close proximity to the beach at 3 p.m., while peak concentrations later in the afternoon/evening were displaced ~400 m offshore by clockwise convective-dispersive transport (Fig. 14). Dispersion further lowered somewhat the peak concentration by midnight, but did transport very low concentrations of *Cryptosporidium* out to about 1000 m (Fig. 15). Continued body-contact recreation, coupled with convective-dispersive transport, will result in significant concentrations of

Cryptosporidium reaching the outlet tower (Fig. 1). Superimposed on this are the inputs distributed across the reservoir from personal watercraft, waterskiiers and other recreators.

While the numerical simulations yielded results that were consistent with available monitoring data, additional studies are needed to adequately quantify the impacts of body contact recreation on water quality in Lake Perris. That is, given the importance of transport processes in defining the exposure and thus the health risks to recreators and consumers, measurements of water currents within the lake, additional monitoring near the beaches and in the main body of the reservoir, and more comprehensive modeling efforts are needed to adequately define the recreator and consumer health risks resulting from body-contact recreation, and to evaluate possible mitigation strategies.

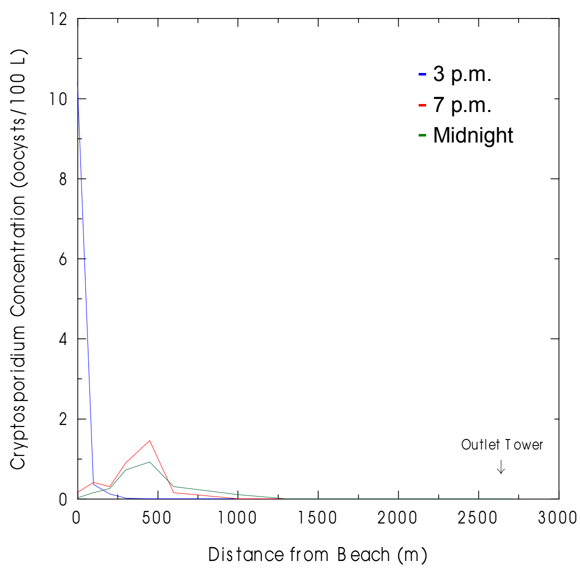


Fig. 15. Cryptosporidium concentrations along transect from Perris Beach to outlet tower.

Conclusions

Body-contact recreational activity is predicted to have significant effects on the pathogen concentrations in all of the SWP reservoirs. Lake Perris is predicted to experience the most substantial impacts due to its high level of recreational use relative to the volume of its epilimnion. Use levels normalized to epilimnetic volume were about 2-4x higher for Lake Perris than the other SWP reservoirs. These high levels of recreational intensity translated to the highest predicted concentrations of pathogens and, correspondingly, the highest consumer risk levels of the SWP reservoirs. The probability of exceeding the EPA target of 1 infections per 10,000 consumers per year was approximately 40% for Silverwood Lake, 45% for Pyramid Lake, 53% for Castaic Lake and 65% for Lake Perris.

Transport simulations conducted for Lake Perris predicted a rather complex circulation pattern within the reservoir that tended to limit offshore dispersion of fecal coliform from beach areas. Simulations predicted fecal coliform concentrations at the Perris Beach that increased substantially through the late morning and early afternoon, peaked near 3 p.m. with concentrations over 100 cfu/100 mL, and then fell sharply in the late afternoon and early evening. Dispersion and inactivation lowered the concentrations to ~2 cfu/100 mL or less by midnight. Because of the longer inactivation half-life, *Cryptosporidium* was predicted to transport further into the reservoir than fecal coliform.

Simulation results were in reasonable accord with available fecal coliform monitoring data. Samples collected at Perris Beach at approximately noon during the summer weekends of 1999 yielded a mean from a log-normal distribution of 15.3 ± 5.3 cfu/100 mL, which was in good agreement with a predicted concentration of 24 cfu/100 mL. Predicted and observed concentrations near the buoy line were also in good agreement, both yielding concentrations below 2 cfu/100 mL. Cumulative probability distribution functions developed from coliform monitoring data indicate that fecal coliform concentrations at approximately noon will exceed the DHS simple sample limit of 400 cfu/100 mL at a probability of about 2.5% for Perris Beach and 5.5% for Moreno Beach. Simulation results do indicate, however, that the probabilities for exceeding the recommended DHS single sample limit will be higher later in the afternoon. Additional studies are needed to better quantify recreator and consumer health risks resulting from body-contact recreation.

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